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Test Report AL 40

NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Washington, D.C. 20007

AERODYNAMIC CHARACTERISTICS OF RECTANGULAR SOLID BODIES OF VARIOUS FINENESS RATIOS AT MACH NUMBERS OF 0.74 AND 1.88

by

George S. Pick and C. Joseph Martin

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AERODYNAMICS LABORATORY

TEST AND EVALUATION REPORT

July 1967

Test Report AL 40

Aerodynamic Characteristics of Rectangular Solid Bodies of Various Fineness Ratios at Mach Numbers of 0.74 and 1.88

AERODYNAMIC CHARACTERISTICS OF RECTANGULAR SOLID BODIES

OF VARIOUS FINENESS RATIOS AT MACH NUMBERS OF

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SYMBOLS

A	axial force, pounds
C_D	drag coefficient (D/Sq)
C_L	lift coefficient (L/Sq)
C_m	pitching moment coefficient ($Pm/Sq\ell$), referred to the body centroid
C_A	axial force coefficient (A/Sq)
C_N	normal force coefficient (N/Sq)
ℓ	body length, inches
D	drag, pounds
L	lift, pounds
L/D	lift drag ratio
M	free-stream Mach number
N	normal force, pounds
Pm	pitching moment, inch-pound
q	free-stream dynamic pressure, psi
S	reference area, square inches (2.25 sq in.)
α	angle of attack, degrees

Abbreviation

FR	fineness ratio

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SUMMARY

Results are presented of a wind tunnel investigation conducted at Mach numbers of 0.74 and 1.88 to determine the aerodynamic characteristics of rectangular solid bodies for fineness ratios (FR) of 1, 2, and 3, between 0° and 90° angles of attack. All the models had the same frontal area of 1.5 by 1.5 inches.

INTRODUCTION

A present day attack aircraft is a carefully designed and optimized system, capable of high speed, extended range, and a high degree of maneuverability. In tactical situations, however, the capabilities of the airplane are greatly compromised because of the present methods employed in carrying and delivering weapons. A great drag penalty is associated with the externally carried armament. Because of the added drag, the combat radius of the loaded aircraft is often substantially less than that of the "clean" vehicle.

Variable sweep-wing aircraft will probably be used with increased frequency in the future. Fuselage mounted weapons seem to offer the greatest advantages for this type of aircraft system and to effectively utilize the fuselage as a weapon carrier, efficient packaging is necessary. The currently used external stores do not package efficiently on the airplane. It is obvious that configurations like cubical or rectangular prisms offer maximum utilization of the stowage area because they can be mounted quite compactly under the fuselage of an aircraft. It is also possible to enclose many different types of weapons and equipment into the same external shape. Such a configuration, with proper fairing, may offer considerable drag reduction relative to the present systems.

A program is underway at the Aerodynamics Laboratory, Naval Ship Research and Development Center, to examine various concepts of weapon configurations, mountings, and separation systems which could improve the performance and delivery of aircraft/weapon systems. It therefore becomes necessary to investigate a number of problems related to the captive flight drag properties, release characteristics, store stability and free flight drag properties of the various weapon concepts.

Aerodynamic properties play a major roll in the separation, stability, and drag characteristics of stores. The purpose of the present investigation is to determine the aerodynamic characteristics of rectangular prism models with FR of 1, 2, and 3 at Mach numbers 0.74 and 1.88 over the angle of attack range of 0° to 90°.

DESCRCRIPTION OF TEST APPARATUS

The force and moment coefficients were obtained in the Naval Ship Research and Development Center (NSRDC) 18-Inch Supersonic Wind Tunnel. This indraft tunnel operates from atmospheric pressure to vacuum with a Mach number range of $0.2 \leq M_{\infty} \leq 4.5$; its detailed characteristics are given in Reference 1.

Mach numbers 0.74 and 1.88 were used in these tests. The force and moment data were taken on the standard five component wall balance of the 18-inch channel, calibrated to the following maximum limits: normal force, 100 pounds; axial force, 100 pounds; pitching and yawing moments, 50 inch-pounds; and rolling moment, 100 inch-pounds. The accuracy of this unit is plus or minus one percent of the full-scale reading. All the loading curves proved to be linear.

MODELS

Mahogany models were used throughout the testing. The basic model was a 1.5-inch cube with a 3/4-inch hole bored into the side to accommodate the mounting sting. This shape was enlarged to the rectangular prisms of FR 2 and 3 while the sting remained at the center of the model. A constant frontal area of 1.5 inch by 1.5 inch was maintained for all models. Figure 1 shows the various fineness ratio models.

TEST PROCEDURE

The interference effects of the sidemounted sting on the measurements of the aerodynamic coefficients were determined prior to testing. It was found that a 0.5-inch diameter sting inside a 0.75-inch outside diameter windshield yielded the most accurate data. In view of this, the shielded configuration was chosen as the most suitable for the investigation. Figure 2 shows one of the rectangular models mounted on the shielded wall balance in the wind tunnel.

Prior to each test series, a Mach number survey was made in the test section to evaluate the flow field and obtain the test Mach number. Within the area of the model location, the Mach numbers 0.74 and 1.88 were maintained within ±0.75 percent.

The test procedure for each run may be summarized as follows:

1. The model was carefully positioned on the sting and leveled as close to horizontal as possible. The exact angle deviation from horizontal (always less than 2°) was then determined by a sensitive leveling device with an accuracy of 0.05°.

2. After the tunnel start, the balance, sting, and model were rotated through an angle of attack range of 0° to 90° with calibrated gear device. An average tunnel run was twenty seconds.

3. The angle of attack and five force components, measured simultaneously, were recorded on magnetic tape via the Beckman 210 readout system. The digital data on the magnetic tape was converted to aerodynamic coefficient form by the computer. A constant reference area of 2.25 square inches was used throughout the test series.

4. The above procedure was followed for FR 1, 2, and 3 at Mach numbers 0.74 and 1.88.

RESULTS AND DISCUSSIONS

Results obtained are shown in Figure 3 through Figure 11 for $M = 0.74$ and Figure 12 through Figure 20 for $M = 1.88$. The average dynamic pressure for $M = 0.74$ is 3.7596 psia ±0.1 percent and for $M = 1.88$, 5.4857 psia ±0.1 percent. Figure 3 shows a comparison of the lift coefficient versus angle of attack at $M = 0.74$ for FR 1, 2, and 3. For the cubical model FR 1, the lift coefficient is slightly negative between $\alpha = 0^\circ$ and 25°, and is zero, and later slightly positive between $\alpha = 25^\circ$ and 45°. Again between $\alpha = 45^\circ$ and 73°, the lift coefficient is negative; it becomes positive at 75° and from a positive maximum at 81°, it drops to a negative value at 90°. The lift coefficients of the FR 2 and 3 models vary in such a way that both increase monotonically from zero until they reach a maximum at about $\alpha = 45^\circ$. The maximum value of the lift coefficient of the FR 3 model is about 85 percent higher than for the FR 2 model. When the angle of attack exceeds 45°, both models stall and the C_L values decrease with increasing angle of attack. Both models have zero lift coefficients at $\alpha = 87^\circ$.

The drag coeffici. .c ve.sus angle of attack plots at $M = 0.74$ (Figure 4) shows that up to $\alpha = 12°$, all three models exhibited equal drag values. The predominance of pressure drag and its dependence on the projected frontal area results in the sinusoidal form of the FR-2 and the FR-3 curves. The slow growth of the sine function for small angles results in the curves being equal for α up to $12°$ where they begin to separate. The cubical model showed almost constant drag characteristics with very slight maximum at about $\alpha = 50°$.

Figure 5 contains the axial force coefficient versus angle of attack data at $M = 0.74$. The values of the coefficients were at their maximum between $\alpha = 0°$ and $20°$ and decreased thereafter. Throughout the angle of attack range, the axial force coefficient values for all three models seem to coincide. This behavior is expected since the body axis system rotates with the model and therefore the projected frontal area relative to this axis systems remains constant.

The normal force coefficient versus angle of attack relationships for the three models at $M = 0.74$ (shown in Figure 6) behave in very much the same fashion as the drag coefficient angle of attack relations (shown in Figure 4).

Figure 7 contains the pitching moment versus angle of attack data. At $\alpha = 0°$, the initial slopes were negative for all three models. After a negative minimum at $\alpha = 5°$, the slopes of the curves for the FR 2 and 3 models became positive and the maximum pitching moment values were attained at $\alpha = 45°$ for the FR 3 model and $\alpha = 55°$ for the FR 2 model. The cubical model reached a negative minimum at $\alpha = 11°$ and the pitching moment coefficient became zero at $\alpha = 45°$. The positive maximum was reached at about $\alpha = 77°$. From this maximum, the curves dropped rather sharply to zero at $\alpha = 90°$. Curves of the other two models reached zero pitching moment coefficient values at $\alpha = 85°$. It should be noted that the maximum pitching moment coefficient of the FR 3 model was 300 percent higher than for the FR 2 model and 700 percent higher than the maximum value of the cube.

The lift to drag ratio versus angle of attack at $M = 0.74$ is shown in Figure 8. The initial slope of the curve for the cubical store model was negative and reached a negative minimum at $\alpha = 10°$; thereafter, the ratio increased to zero and remained substantially zero for the $\alpha = 10^\circ$ to 90° angle of attack range. The initial slope of the FR 2 model was positive until it reached its maximum value at $\alpha = 25^\circ$. The lift to drag ratio remained at the maximum value up to $\alpha = 45^\circ$ and then slowly decreased to a zero value at $\alpha = 90^\circ$. The lift to drag curve for the FR 3 began with an initial positive slope, reached its maximum at $\alpha = 25^\circ$ (this maximum is 75 percent larger than the maximum of the FR 2 model), and hereafter decreased monotonically to L/D = 0 value at $\alpha = 90^\circ$.

Figure 9 shows the lift to drag ratio data plotted against the lift coefficient at M = 0.74. This graph, as well as Figures 11 and 12, are presented in two parts. Part one presents the data between the 0° to 45° angle of attack range, and part two shows the lift to drag ratio in the 45° to 90° angle of attack range. In part one, the data for all three fineness ratios fall along a single line between $C_L = -0.1$ and $C_L = 0.4$. At this point the slope of the curve corresponding to the FR 2 model decreases until the curve reaches a maximum value at $C_L = 1.1$. The graph of the higher fineness ratio model exhibits a higher slope than the previous curve and increases until $C_L = 1.7$ at which point the curve reaches a maximum value which is 70 percent higher than the previous maximum and declines thereafter.

In part two, the curves monotonically decrease from a higher L/D value at higher lift coefficients toward the zero L/D ratio at $C_L = 0$.

Figure 10 shows the drag versus lift coefficients at M = 0.74. The data points for the cubical model are clustered around the zero value throughout the entire angle of attack range. The data for the higher fineness ratio models show an increase toward increasing C_L at the 0° to 45° angle of attack range, and a further increase in C_D, even when the lift coefficients start to decrease beyond the 45° angle range toward the 90° angle of attack.

The pitching moment coefficient versus lift coefficient curves are shown in Figure 11 for M = 0.74. Again, the data for the cubical model are clustered around the zero values for the entire range. The C_m values for both fineness ratio models increase nearly linearly with increasing C_L in the $\alpha = 0^\circ$ to 45° range and decrease linearly in the $\alpha = 45^\circ$ to 90° range.

Figure 12 through Figure 15 and 17 contain the lift, drag, axial and normal force coefficients, and lift to drag ratio data as functions of the angle of attack at M = 1.88. The general behavior of these curves are very similar to the ones on Figures 3 through 6, and 8 discussed previously; for brevity, they will not be described here.

The pitching moment data as function of the angle of attack and fineness ratio are plotted in Figure 16 for M = 1.88. The higher fineness ratio models experience relatively large negative pitching moments at initial angles of attack up to 25°. All three curves cross the $C_m = 0$ value at $\alpha = 30°$ and the higher fineness ratio models reach positive maximums at around $\alpha = 63°$. The maximum value of C_m of the highest fineness ratio model is 170 percent higher than the intermediate and 800 percent higher than the cubical model.

Figures 18 and 19 contain the lift to drag ratio and drag coefficient versus C_L graphs. Since the general behavior of these curves are very similar to the ones in Figures 9 and 10 (discussed previously), they will not be described here.

The pitching moment versus lift coefficient graphs for M = 1.88 are shown in Figure 20. The general behavior of the curves differ somewhat from their counterparts in Figure 11. There is a decrease in C_m values increasing C_L up to 0.8 at the lower α range, followed by curves of positive slope. In the higher α range the curves reach maximums at some relatively high C_L values and thereafter decrease toward $C_m = 0$.

If one compares the maximum values of the lift, drag, and pitching moment coefficients for M = 0.74 and 1.88, it is evident that, while the drag values stayed substantially the same in both Mach numbers, the lift coefficients are reduced on the average by 22 percent at M = 1.88 relative to M = 0.74 and so the lift to drag ratio is reduced by roughly the same amount at M = 1.88.

In the case of the pitching moment coefficient, the situation is somewhat different because at M = 1.88 the higher fineness ratio models experience a relatively large negative pitching moment up to $\alpha = 25°$.

This does not occur for $M = 0.74$. Secondly, the average maximum of the pitching moment coefficient is 70 percent below the maximum for $M = 0.74$. Thirdly, at $M = 1.88$ the pitching moment curves of all three models cross the $C_m = 0$ line at $\alpha = 30°$. This phenomenon does not occur at $M = 0.74$ for the higher fineness ratio models.

One of the consequences of the above phenomenon is the different behavior of the C_m versus C_L curves at $M = 0.74$ and $M = 1.88$ for both angle of attack ranges. While at $M = 0.74$ the general tendency of these curves is to increase monotonically with increasing C_L, at $M = 1.88$ there is a general decrease in C_m values up to 0.8 at the $\alpha < 45°$ regime. For the $45° < \alpha < 90°$ range at $M = 1.88$, the curves reach maximum values at certain points beyond which they decrease in value. This was totally absent in the respective curves in Figure 11.

Aerodynamics Laboratory
Naval Ship Research and Development Center
Washington, D. C.
June 1967

REFERENCE

1. Ziegler, Norman G. The David Taylor Model Basin Gas Dynamics Wind Tunnel Facility. Wash., Jul 1963. 20 p. incl. illus. (David Taylor Model Basin. Aero Rpt. 1027)

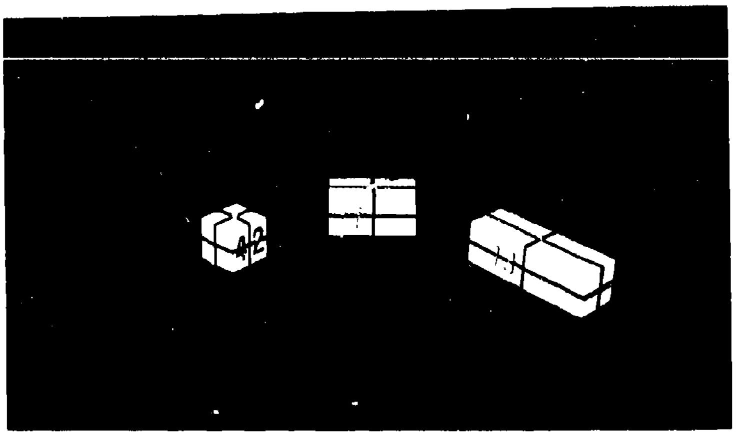


Figure 1 - Representative Models of Various Fineness Ratios

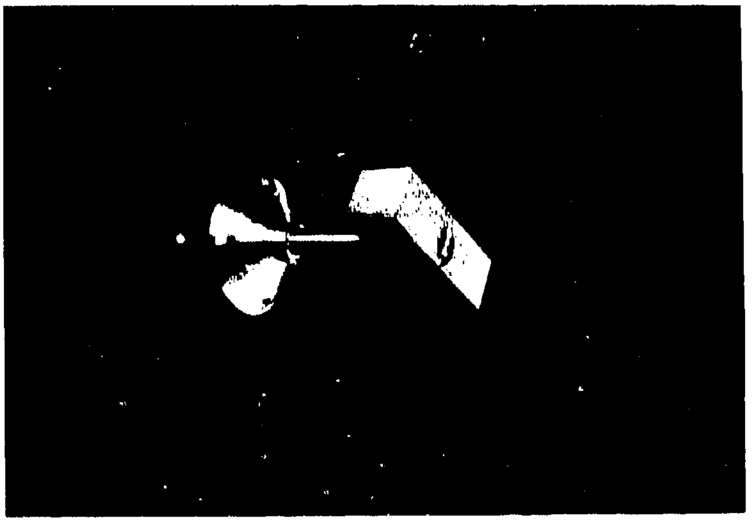


Figure 2 - Tunnel Setup of a Rectangular Model Mounted on the Wall Balance Using the Windshield

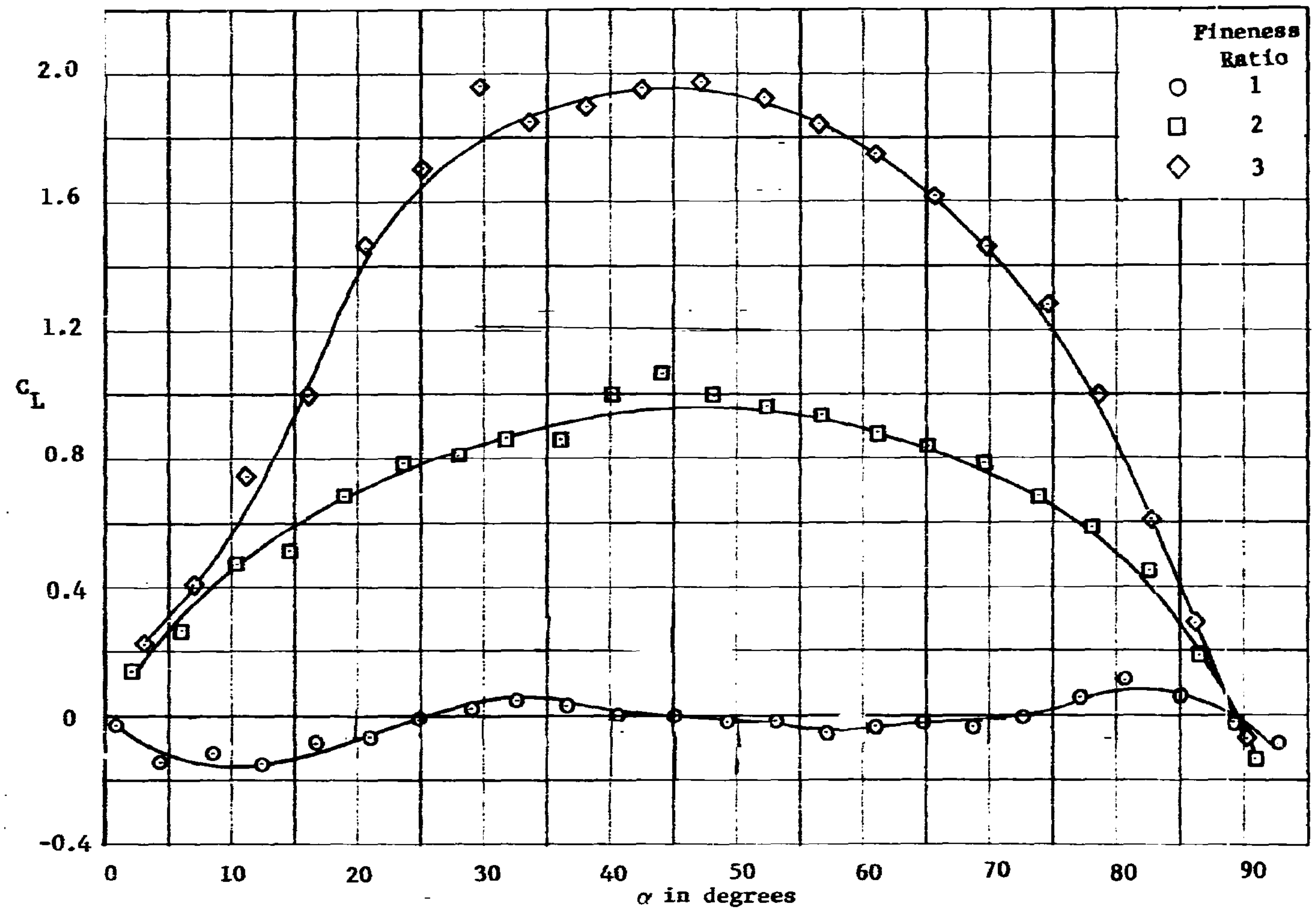


Figure 3 - Lift Coefficient Versus Angle of Attack at M = 0.74

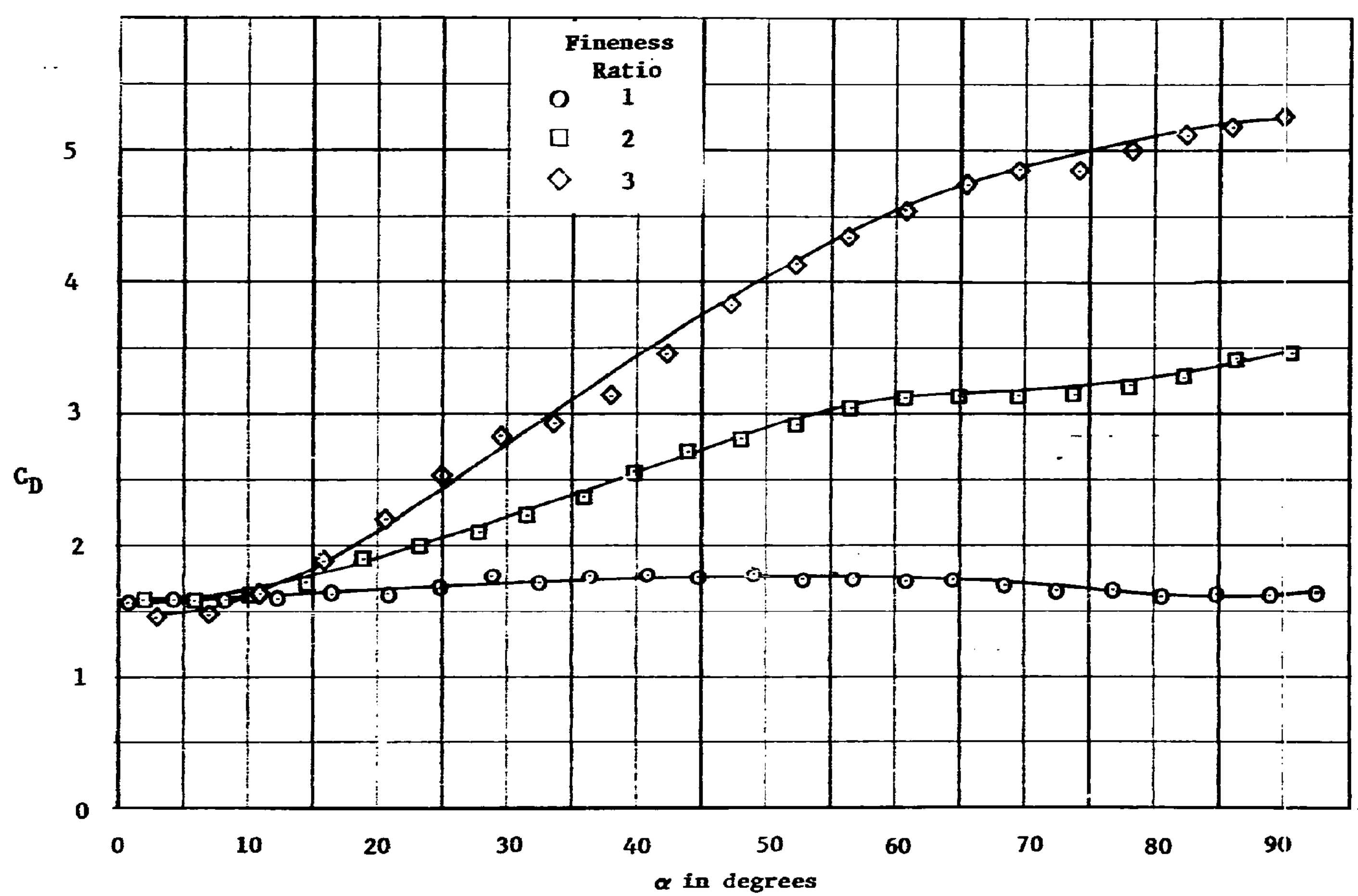


Figure 4 - Drag Coefficient Versus Angle of Attack of M = 0.74

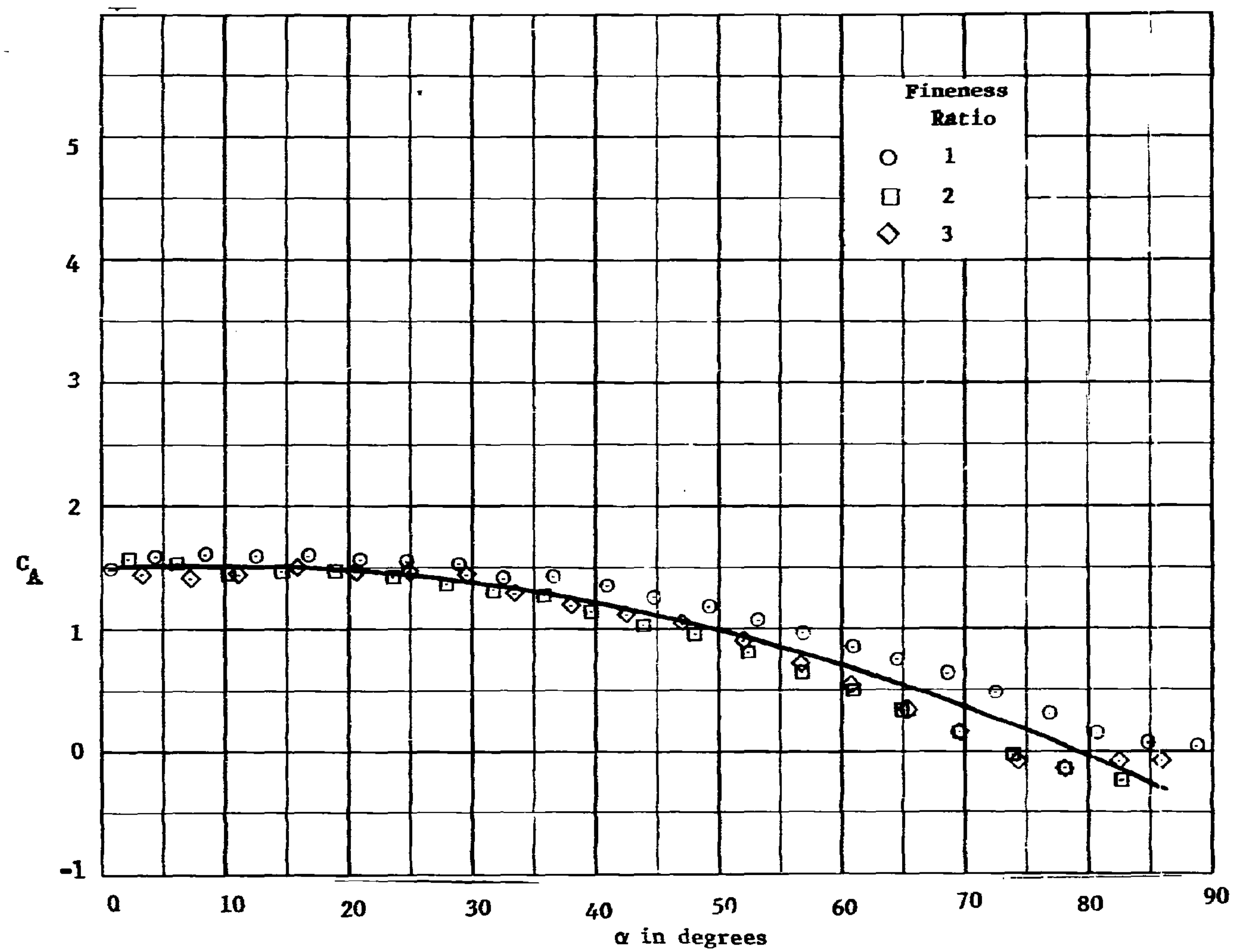


Figure 5 - Axial Force Coefficient Versus Angle of Attack at M = 0.74

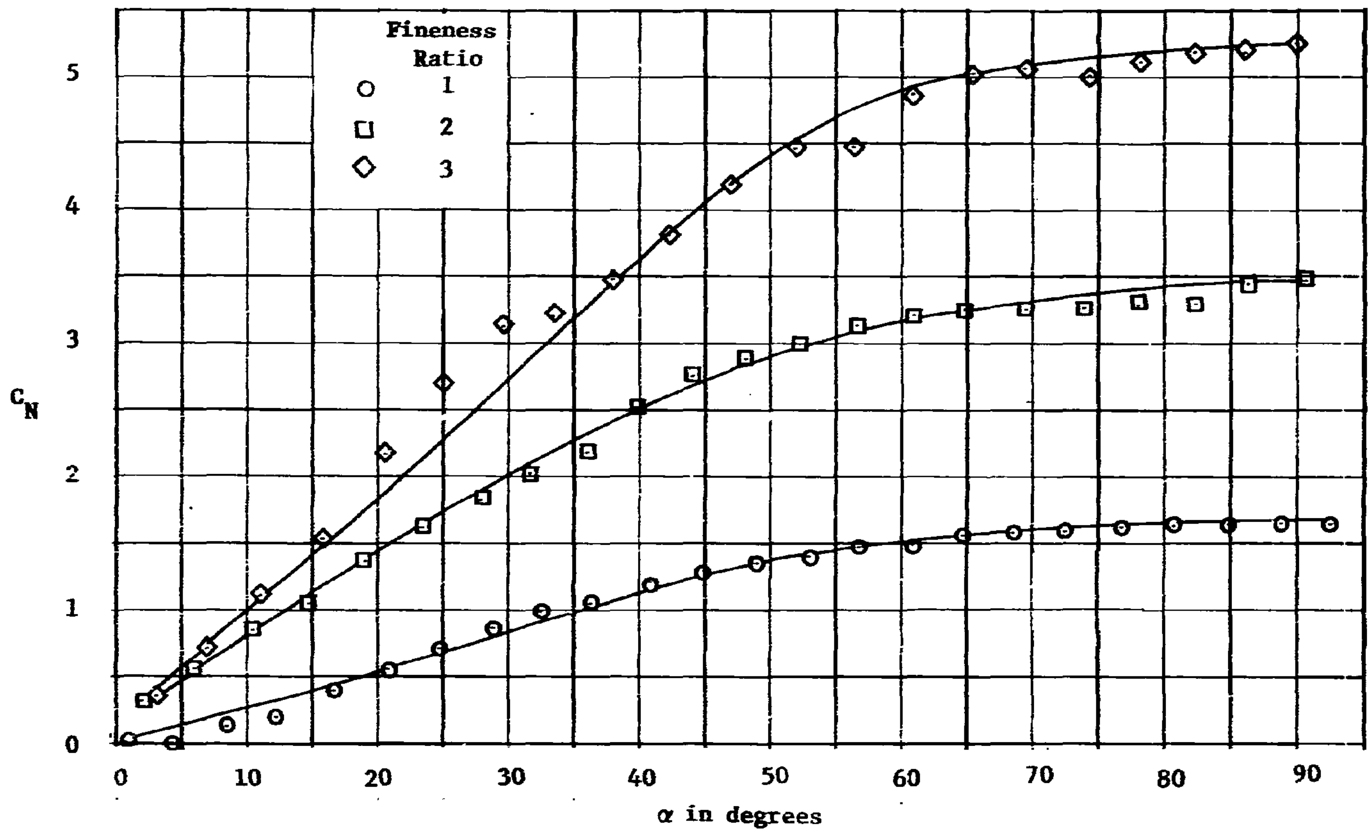


Figure 6 - Normal Force Coefficient Versus Angle of Attack at M = 0.74

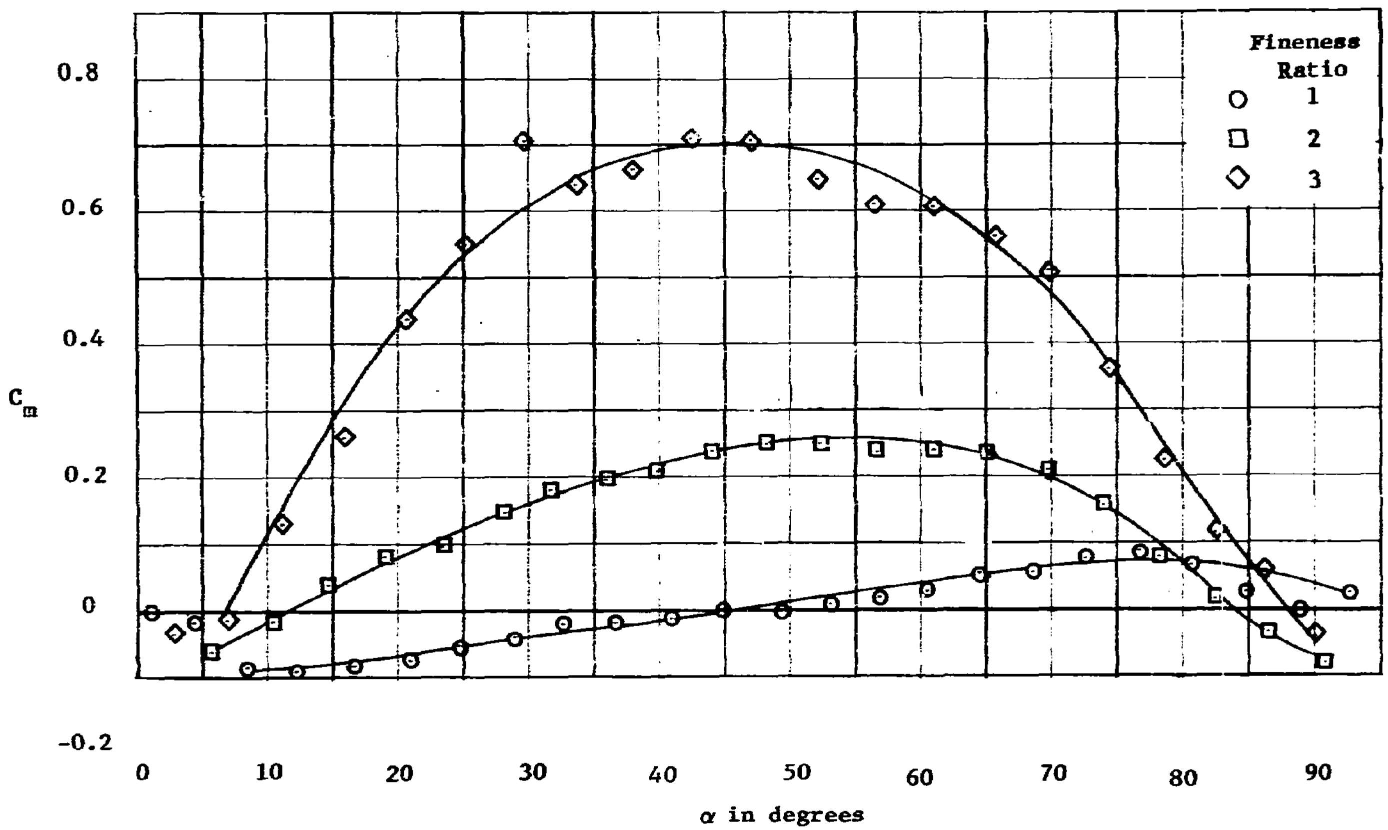


Figure 7 - Pitching Moment Coefficient Versus Angle of Attack at M = 0.74

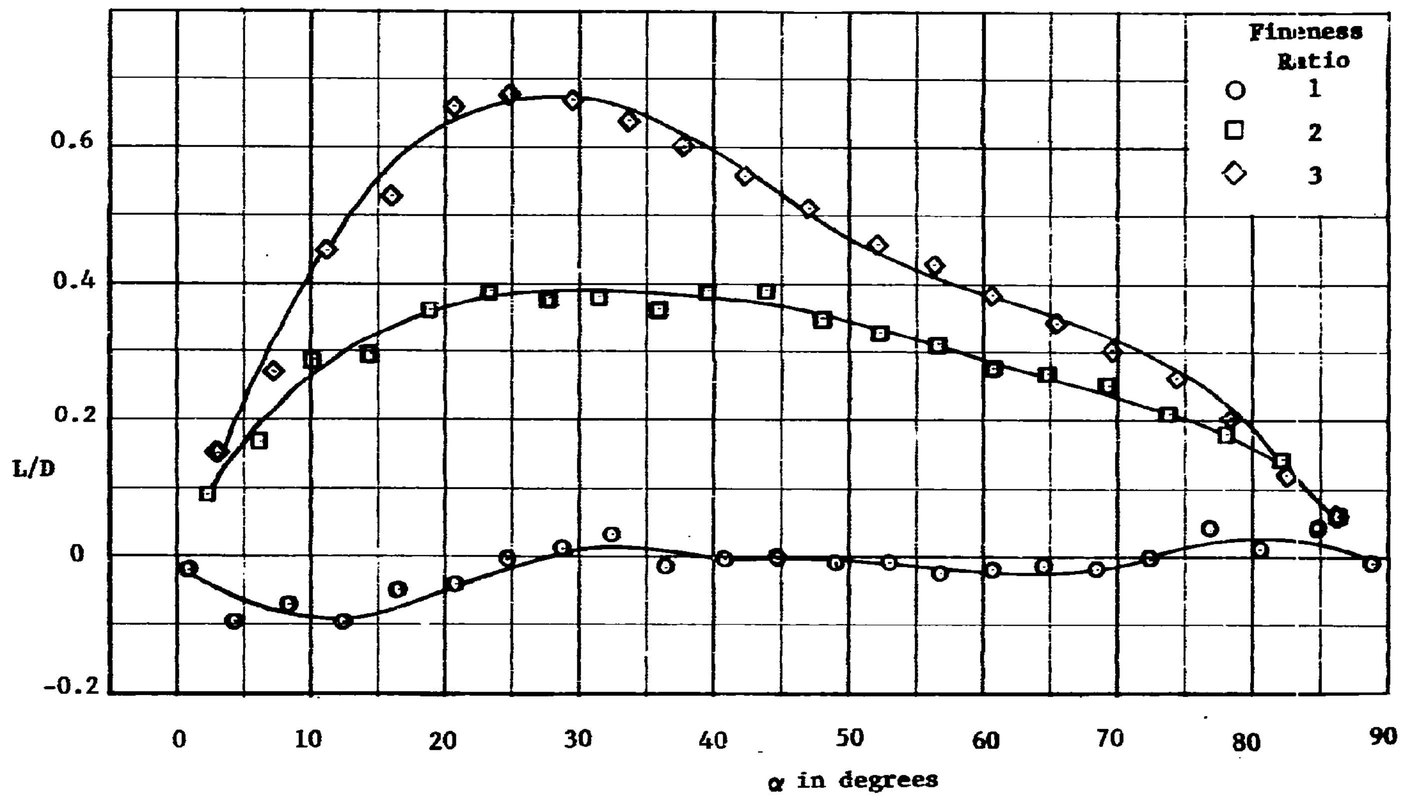
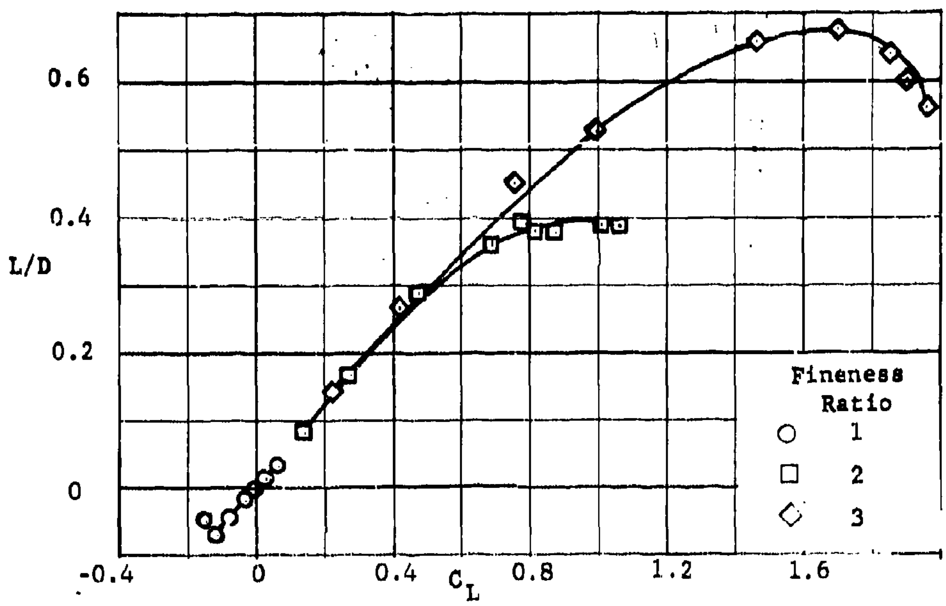
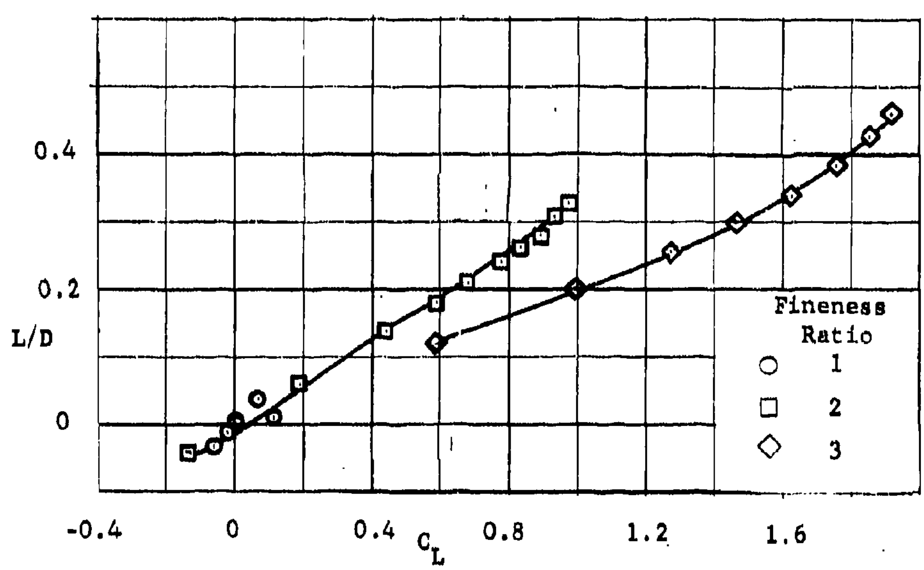


Figure 8 - Lift to Drag Ratio Versus Angle of Attack at M = 0.74

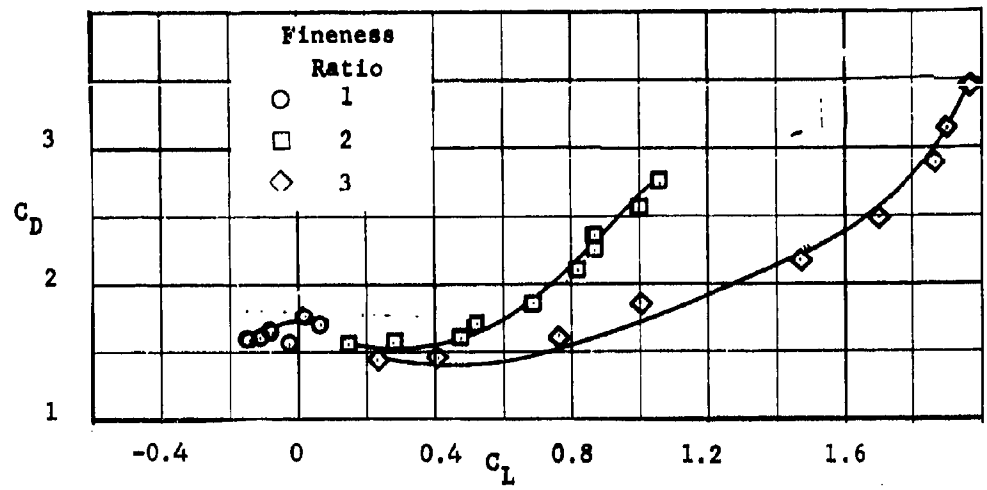


(a) Angle of Attack 0° to 45°



(b) Angle of Attack 45° to 90°

Figure 9 - Lift to Drag Ratio Versus Lift Coefficient at M = 0.74



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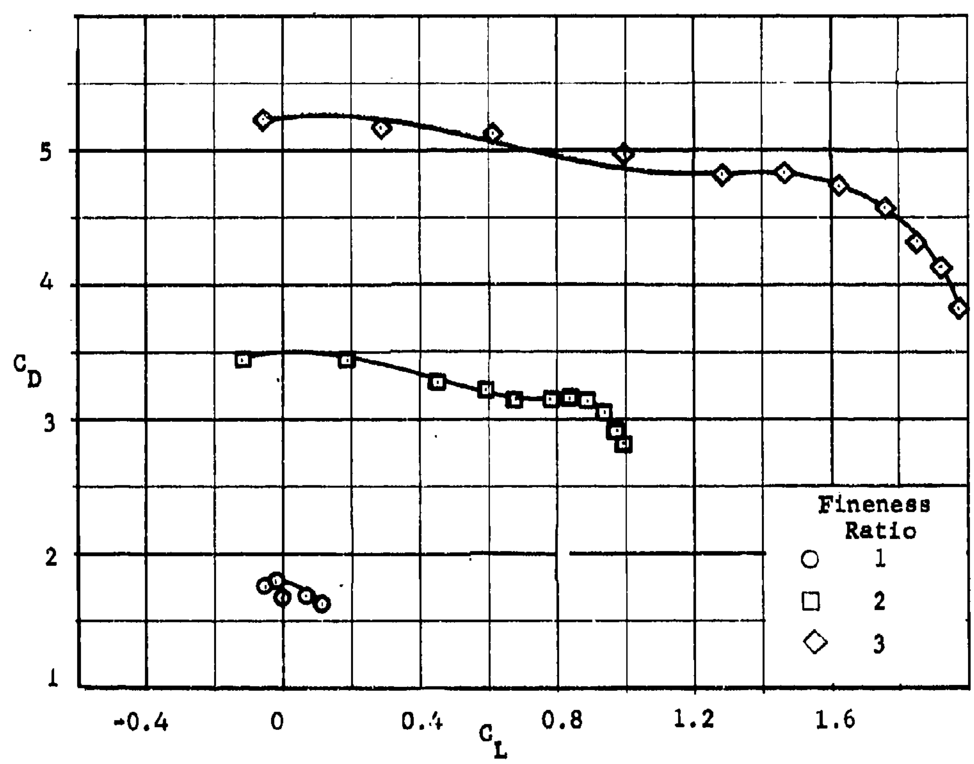
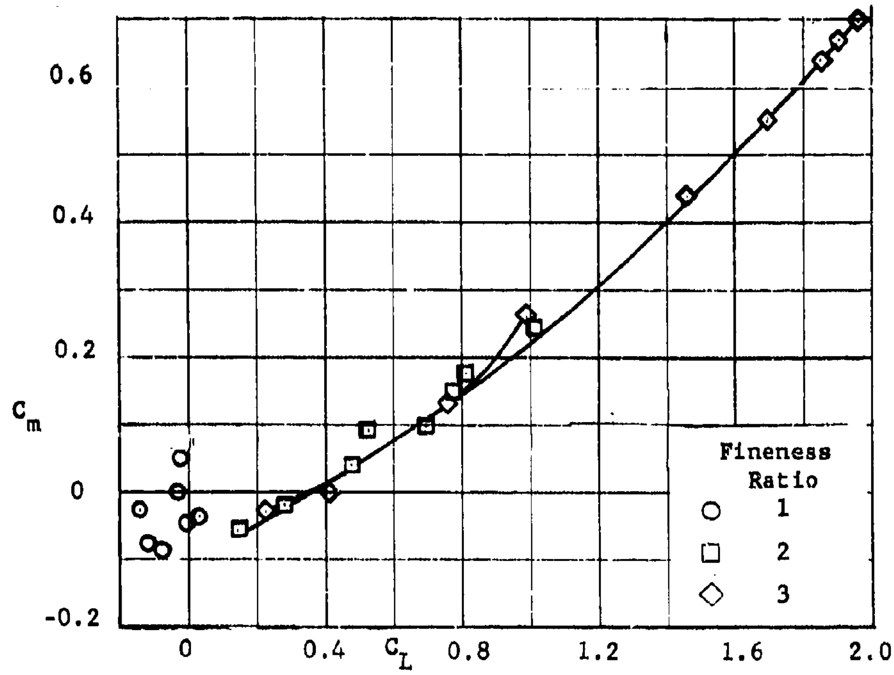


(b) Angle of Attack 45° to 90°

Figure 10 - Drag Coefficient Versus Lift Coefficient at M = 0.74



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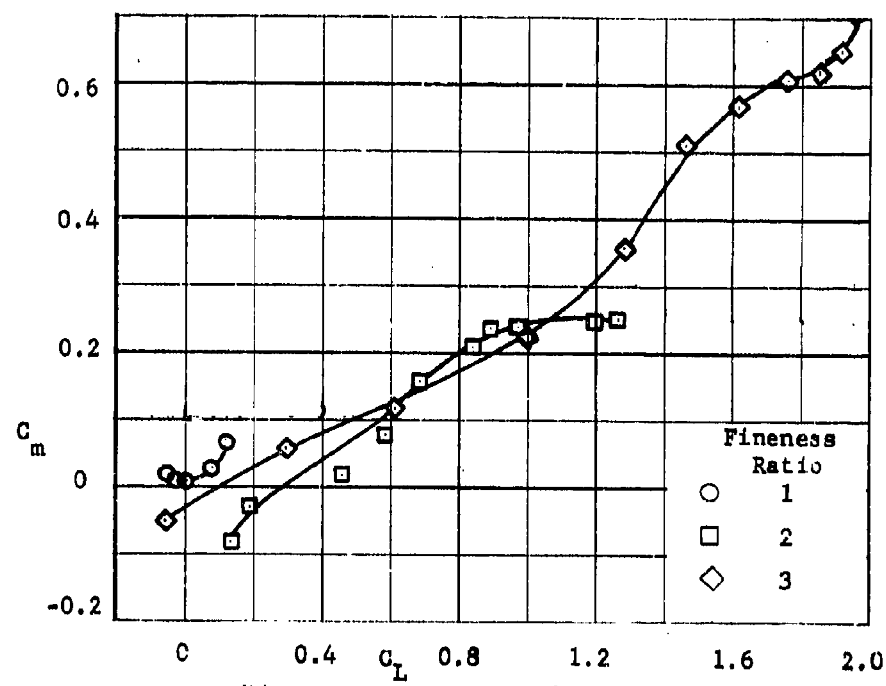


(b) Angle of Attack 45° to 90°

Figure 11 - Pitching Moment Coefficient Versus Lift Coefficient at M = 0.74

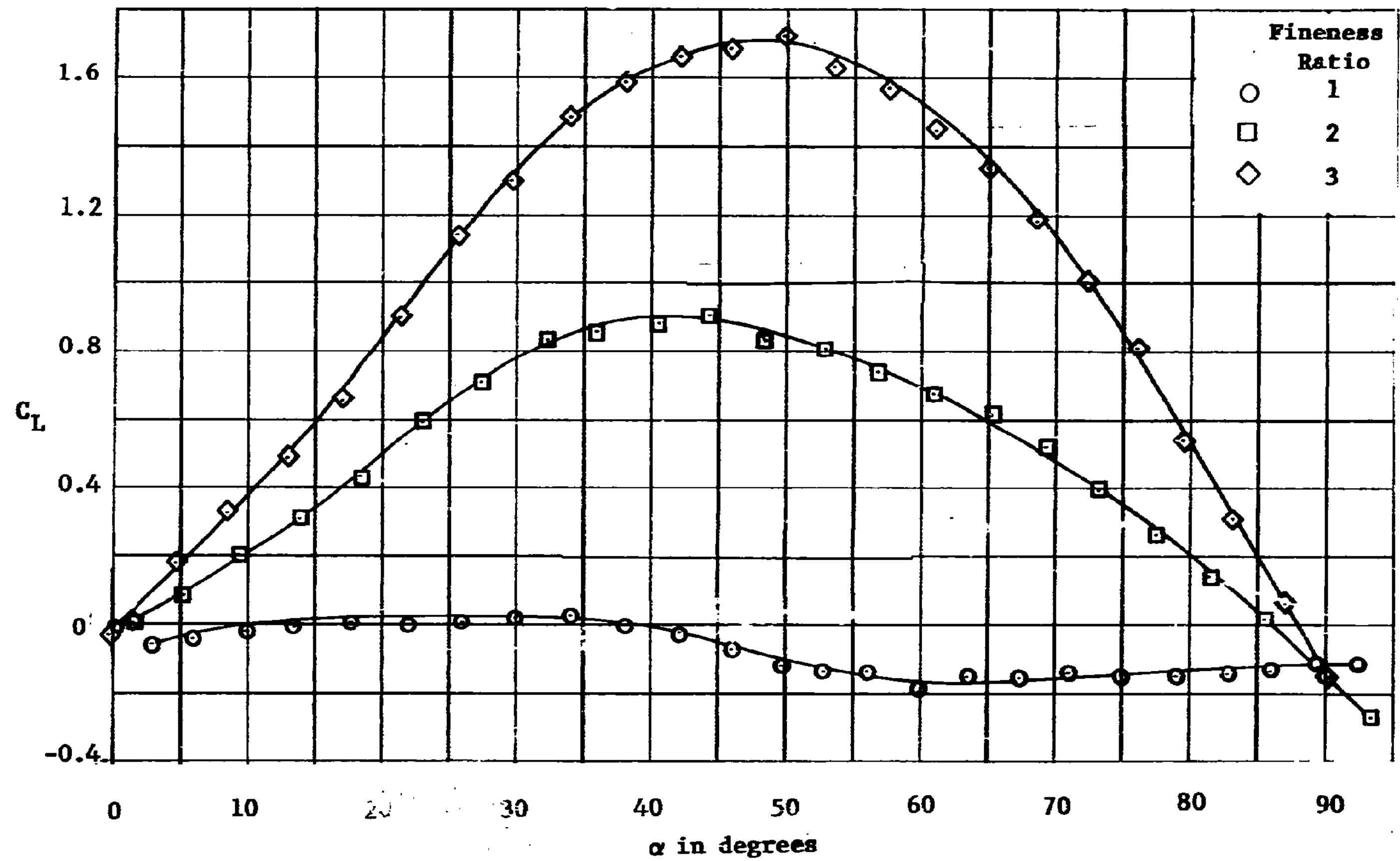


Figure 12 - Lift Coefficient Versus Angle of Attack at M = 1.88

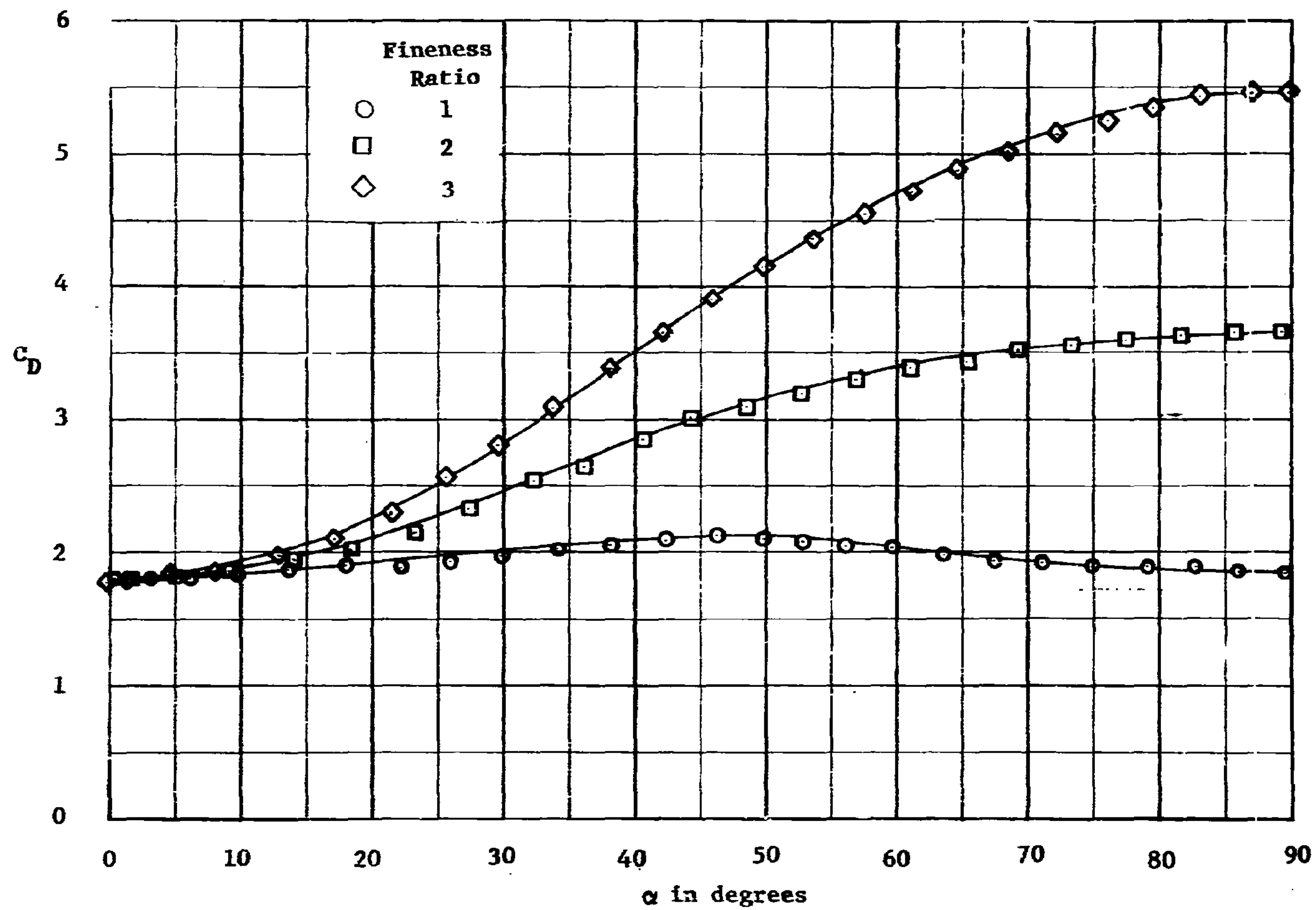


Figure 13 - Drag Coefficient Versus Angle of Attack at M = 1.88

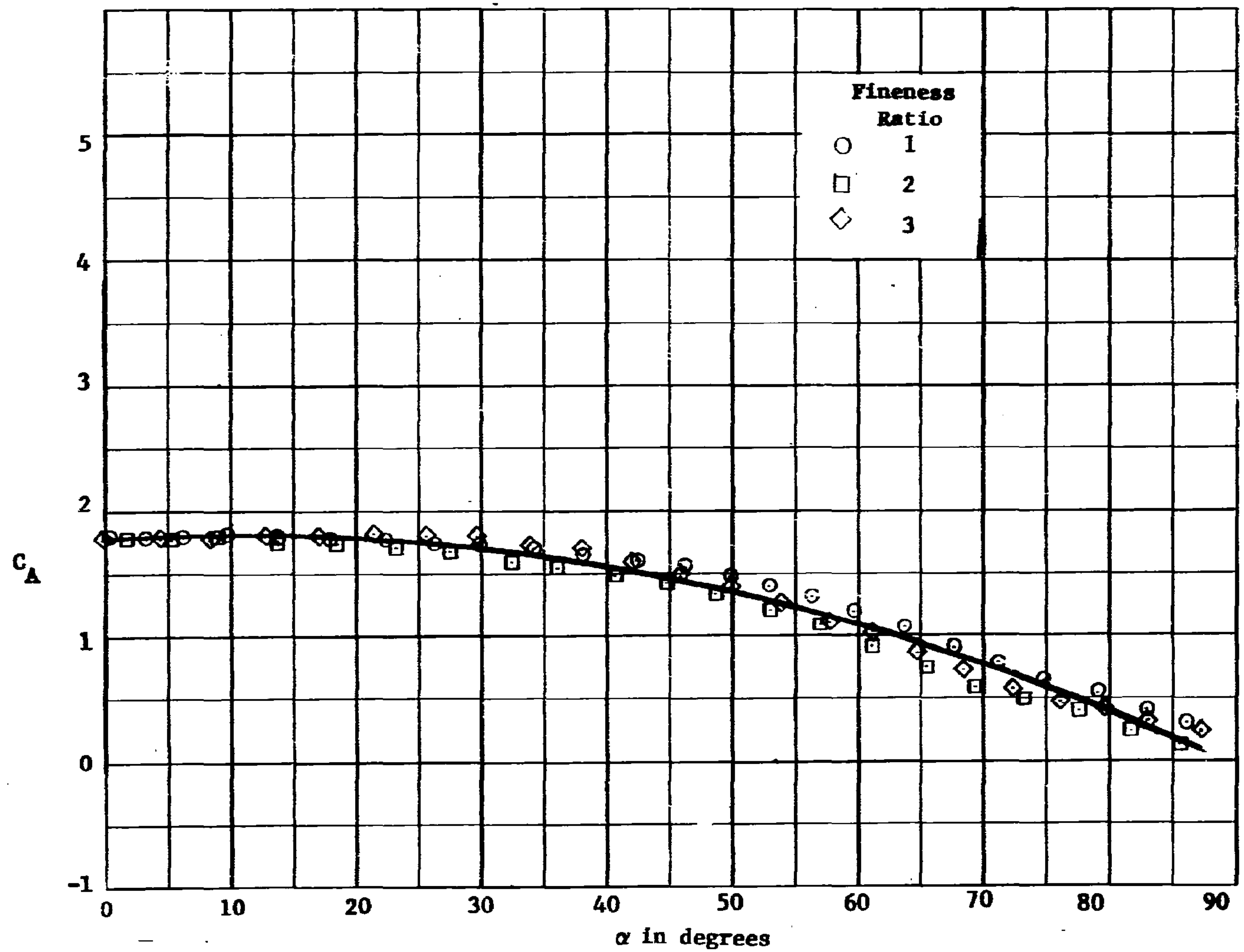


Figure 14 - Axial Force Coefficient Versus Angle of Attack at M = 1.88

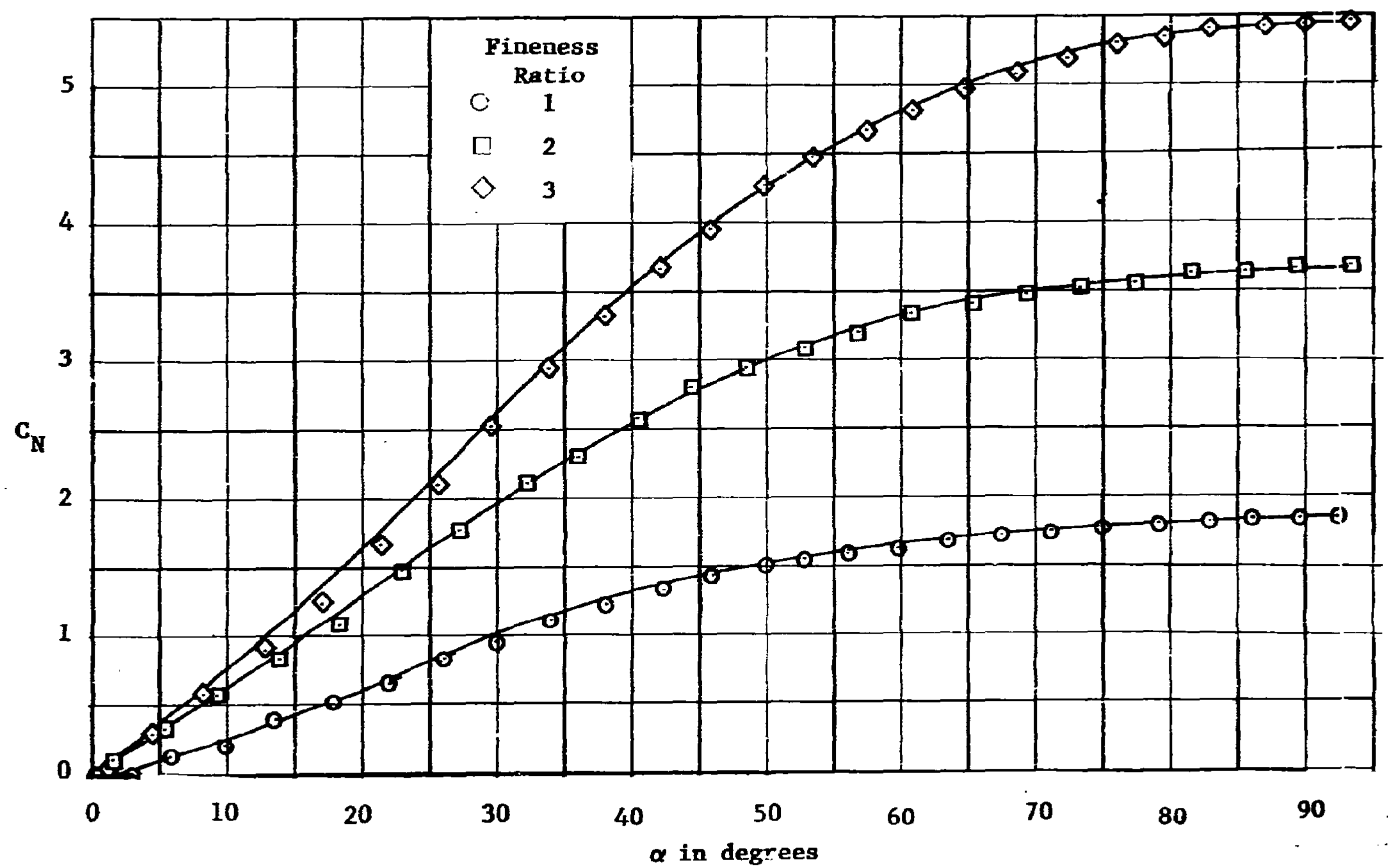


Figure 15 - Normal Force Coefficient Versus Angle of Attack at M = 1.88

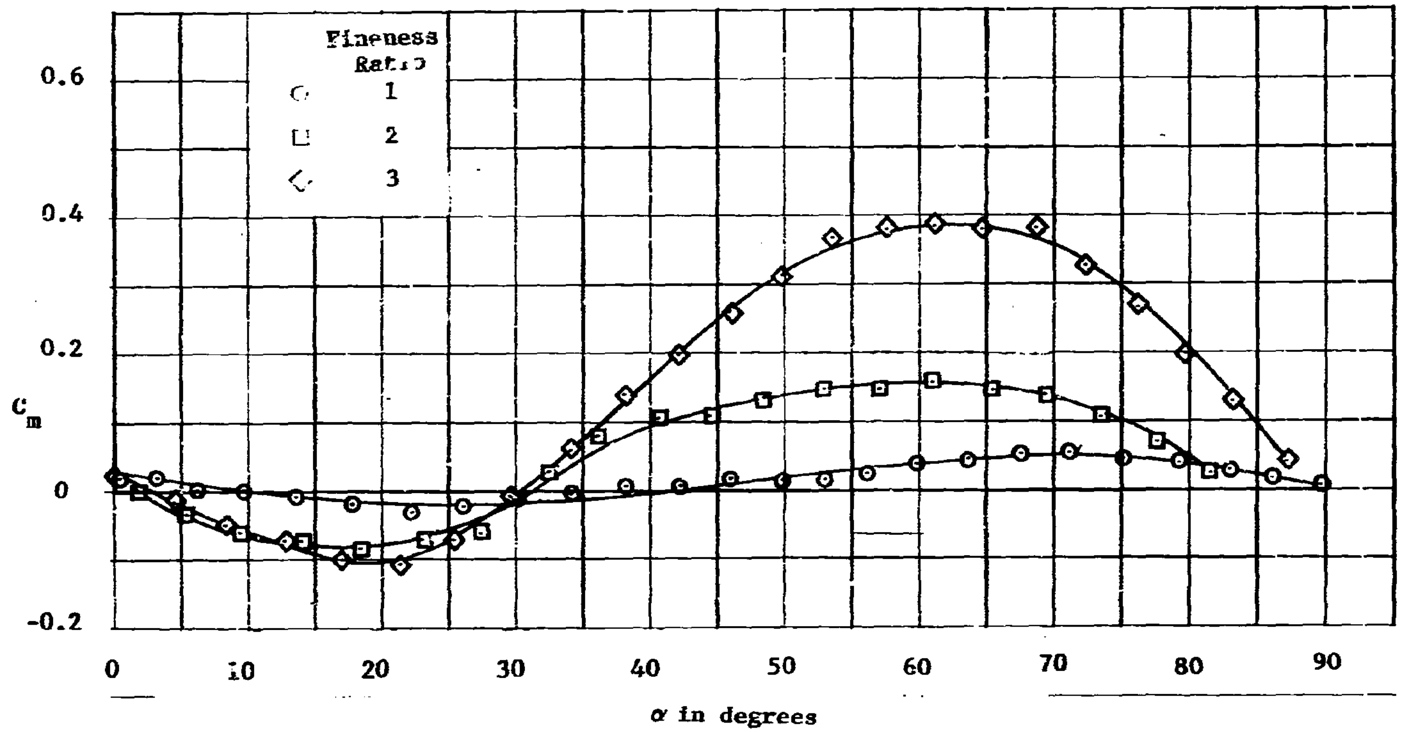


Figure 16 - Pitching Moment Coefficient Versus Angle of Attack at M = 1.88

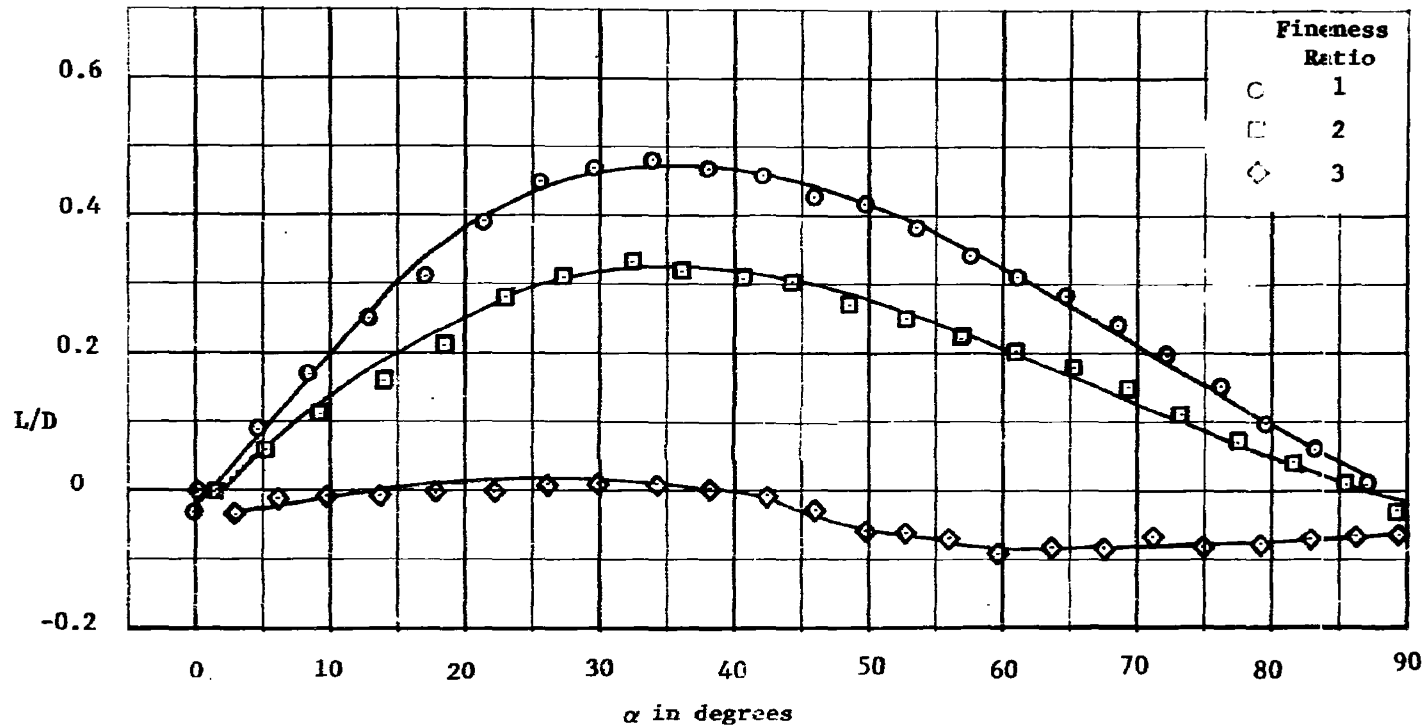
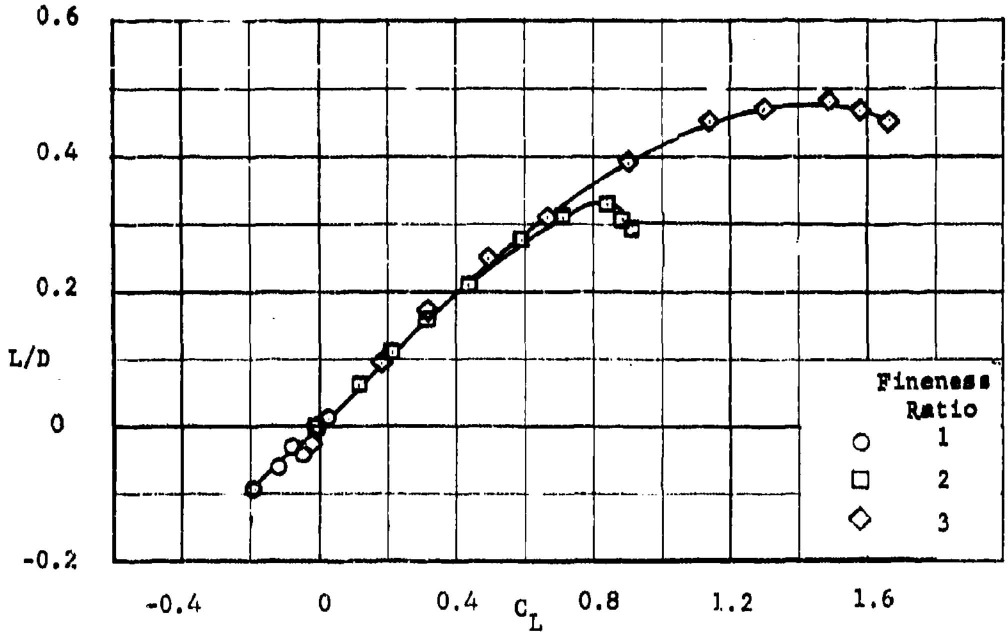
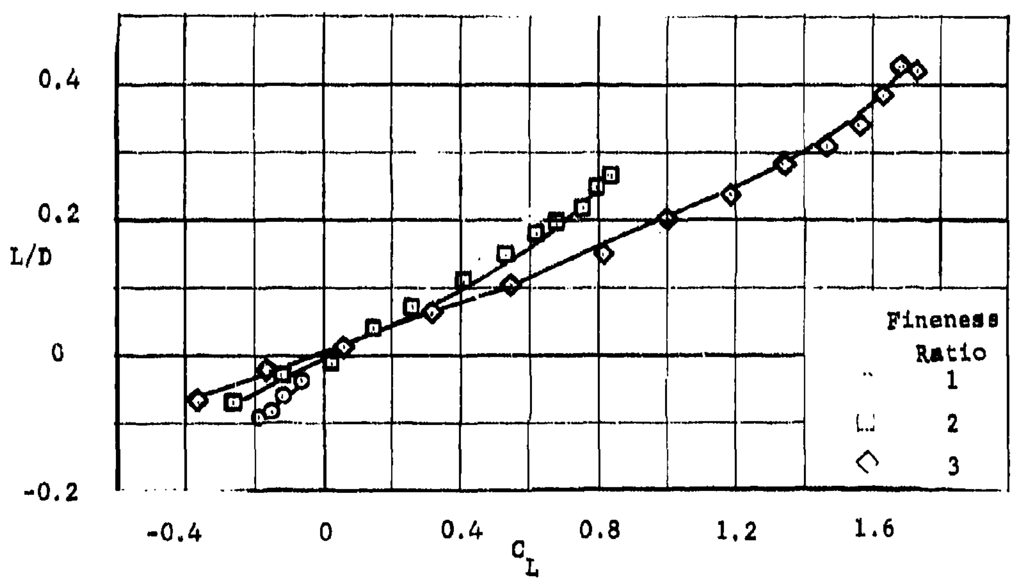


Figure 17 - Lift to Drag Ratio Versus Angle of Attack at M = 1.88

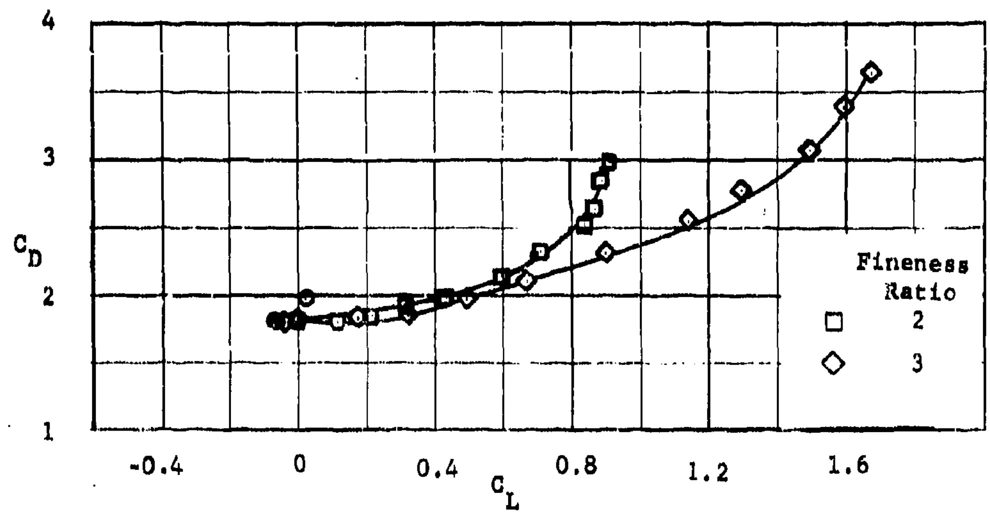


(a) Angle of Attack 0° to 45°

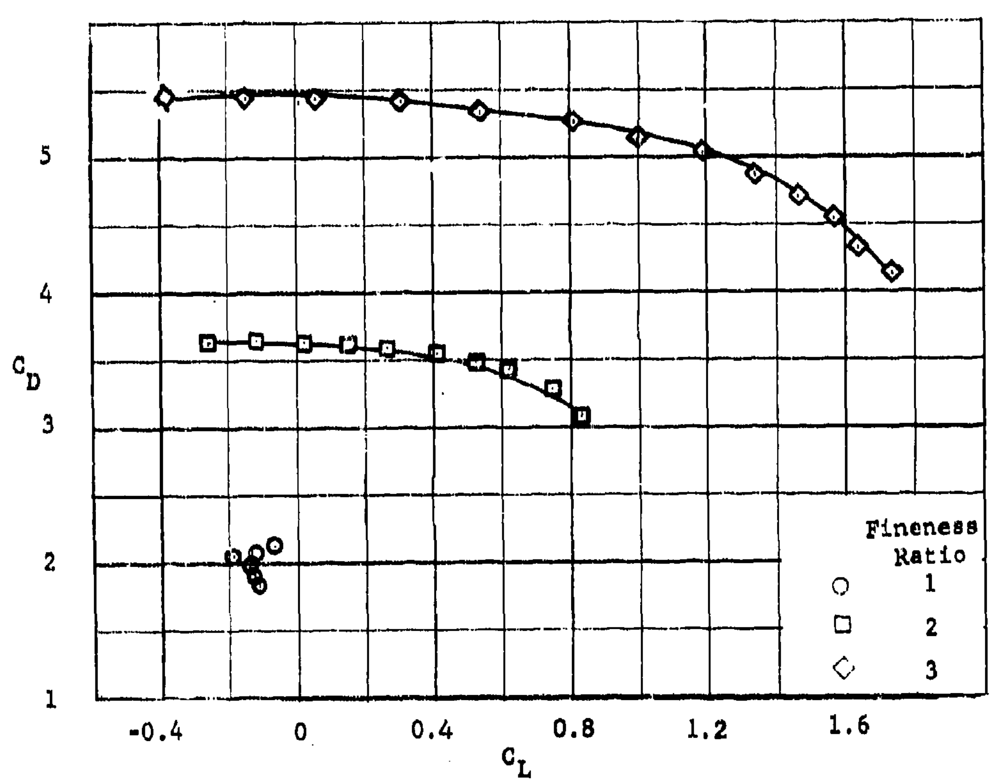


(b) Angle of Attack 45° to 90°

Figure 18 - Lift to Drag Ratio Versus Lift Coefficient at M = 1.88

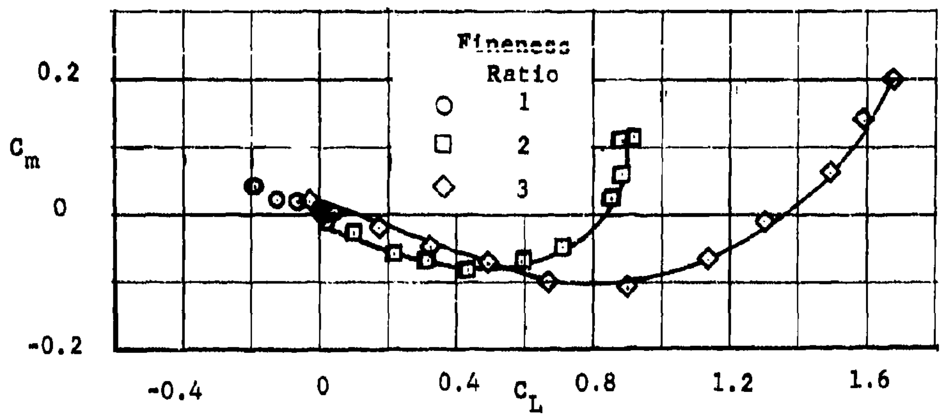


(a) Angle of Attack 0° to 45°

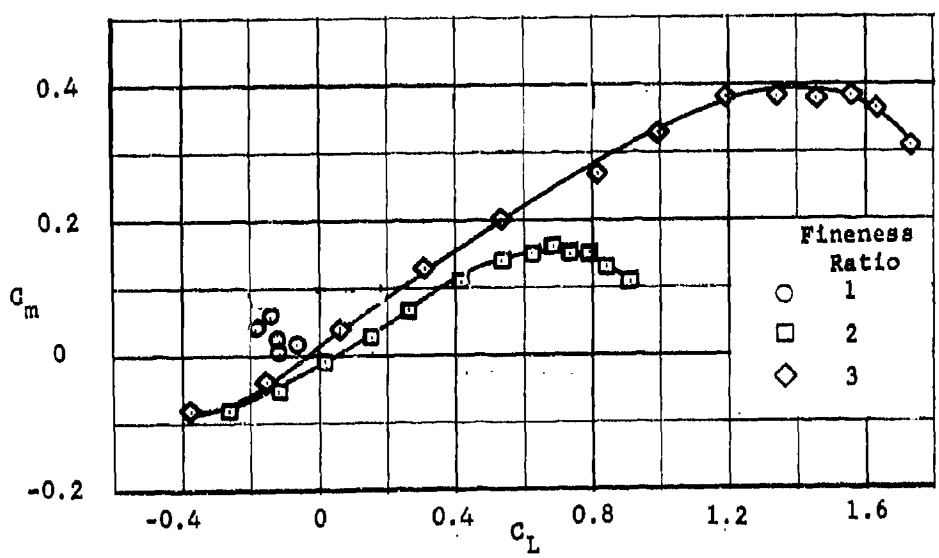


(b) Angle of Attack 45° to 90°

Figure 19 - Drag Coefficient Versus Lift Coefficient at M = 1.88



(a) Angle of Attack 0° to 45°



(b) Angle of Attack 45° to 90°

Figure 20 - Pitching Moment Coefficient Versus Lift Coefficient at M = 1.88

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Aerodynamics Laboratory Naval Ship Research and Development Center Washington, D. C. 20007	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

AERODYNAMIC CHARACTERISTICS OF RECTANGULAR STORES OF VARIOUS FINENESS RATIOS AT MACH NUMBERS OF 0.74 AND 1.88

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

George S. Pick and C. Joseph Martin

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
July 1967	28[iv]	1

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. ZR 011-0101	Test Report AL 40
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d. NSRDC Problem 650-149	

10. DISTRIBUTION STATEMENT

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Chief of Naval Material Department of the Navy Washington, D. C. 20360

13. ABSTRACT

Results are presented of a wind tunnel investigation conducted at Mach numbers of 0.74 and 1.88 to determine the aerodynamic characteristics of rectangular solid bodies for fineness ratios (FR) of 1, 2, and 3, between 0° and 90° angles of attack. All the models had the same frontal area of 1.5 by 1.5 inches.

Unclassified

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Supersonic Flow						
Aerodynamic Characteristics (Bodies)						
Aerodynamic Coefficients (Bodies)						
Cubical Models						
Rectangular Models						

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PITCHING
MACH NO. EFFECTS
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Aerodynamics Laboratory
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by

George S. Pick and C. Joseph Martin

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